Online Calculation of Guide Rings for Hydraulic Cylinders

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Outline

Guide Rings – General Information / Introduction

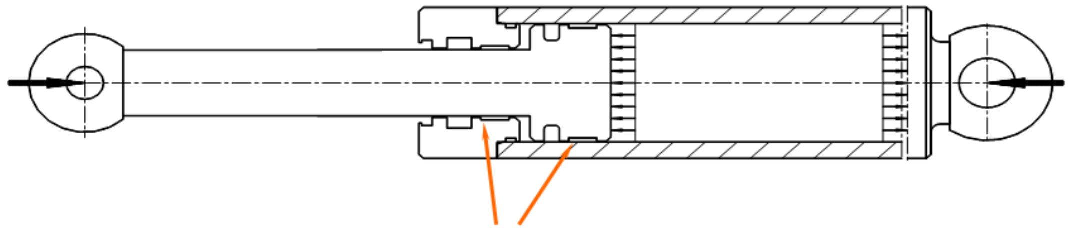
- Hydraulic cylinders often have to operate in very aggressive environments and in many cases faced with side loads.
- Guide rings should withstand this side loading of the cylinder.
- Side load can occur due to several reasons, e.g. by misalignment, clearance and imperfection of the components or when a force strains the cylinder in an abnormal manner.

- The task of the guide rings is to resist the lateral load and to maintain precise guidance as possible.
- Guide ring material must be robust enough to resist compressive forces during side loading.

Guide Rings – General Information / Introduction

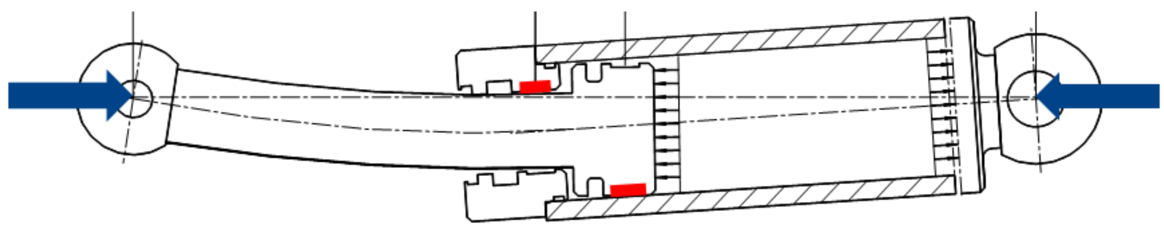
Load examples:

Hydraulic cylinder ideally should operate without side load



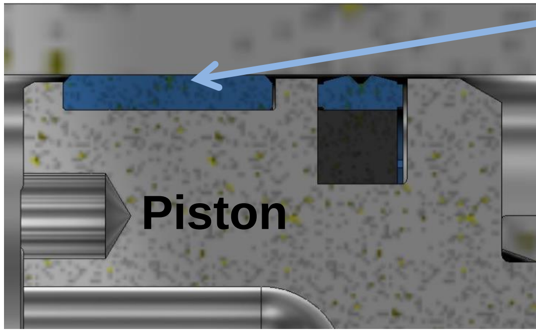
guide rings are not under stress and are guiding the cylinder as it reciprocates

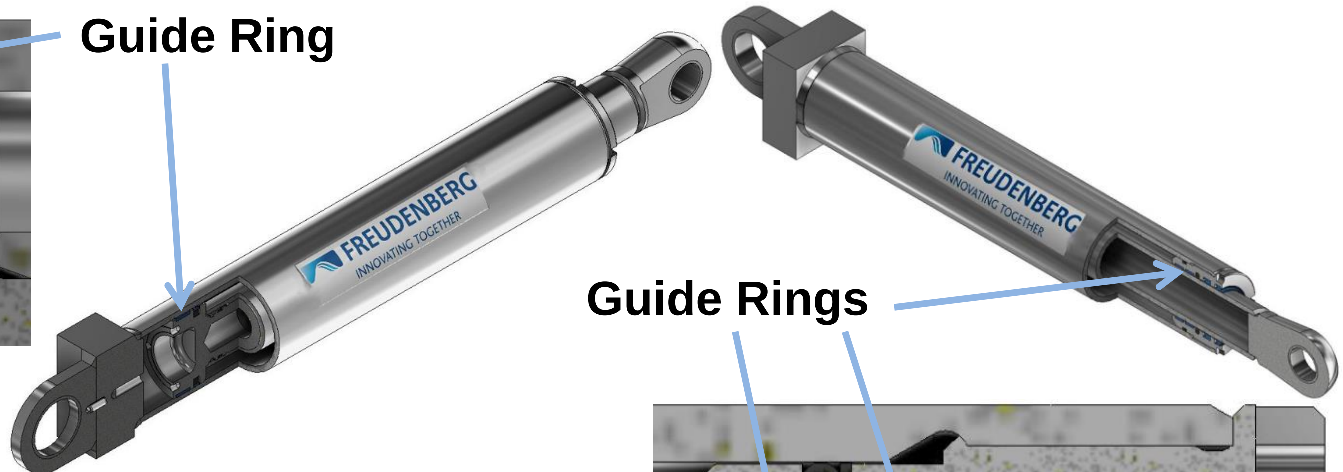
Reality: Side load is not always avoidable

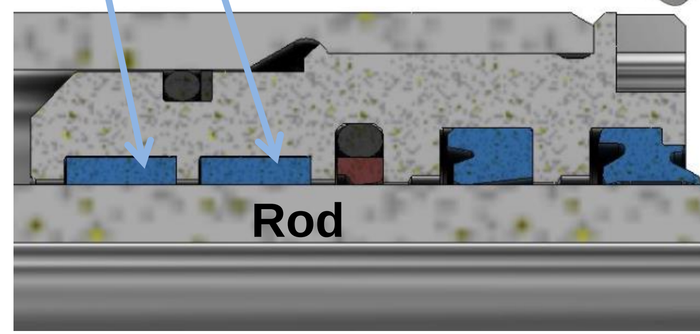


guide rings under high stress should resist the side load

Guide Rings – General Information / Introduction







- Ideally hydraulic cylinders need accurate guidance throughout their operating life.
- Metallic contact between the reciprocating metal components (rod/piston) and the counter surfaces must be avoided.
- Misaligned parts can influence the load capacity of the hydraulic cylinder.
- The guide rings (material, size, geometry, surface, quality) can effect the bending stiffness of the actuator and also the lifetime.

Guide Rings – Synthetic Materials

Most commonly used guide ring synthetic materials are:

Fabric-laminated thermoset (duroplast) materials, reinforced thermoplastics and PTFE (which is not a subject in this presentation)

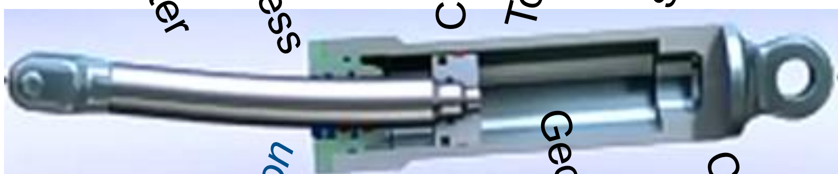
- Fabric-Laminated Thermoset Materials: Thermoset plastics (phenolic-/epoxy-resigns) with ▶superior heat resistance offer ▶good dimensional stability and ▶resist water absorption. Increased in strength when manufactured with reinforcing materials such as a fabric weave. ▶Highest side load capability.

- Reinforced Thermoplastics: Most commonly used is PA/Nylon, available in many types offering ▶excellent fatigue resistance, ▶hydraulic fluid compatibility, ▶heat resistance, ▶compressive strength and impact resistance. Premium PA/Nylons are formulated to resist water absorption.

For lower work load, but low friction:

- PTFE has ▶excellent friction characteristics and ▶good resistance to high temperatures and chemicals. However, only minor side loads are permitted. Within certain limits, increase in strength is possible by adding fillers such as bronze particles, glass fibres, carbon fibres etc.

Demarcation to the State of the Art
(regarding calculations of the entire system hydraulic cylinder)



Hoblit: Critical buckling for hydraulic actuating cylinders. 1950

Seshasai: Stress analysis of hydraulic cylinders. 1975

Bennett: A calculation of piston rod strength. 1978

Ravishankar: Finite element analysis hydraulic cylinders 1980

Chai Hong Yoo: Column loadings on telescopic power cylinders. 1986

Baragetti / Terranova: Limit load evaluation of hydraulic actuators. 1999

Baragetti / Terranova: Bending behaviour of double- acting hydraulic actuators. 2001

ISO/TS 13725. 2001

Yishou / Wenwei: Stability analysis for hydraulic hoist cylinder. 2004

Gamez-Montero: Misalignment effects on the load capacity of a hydraulic cylinder. 2008

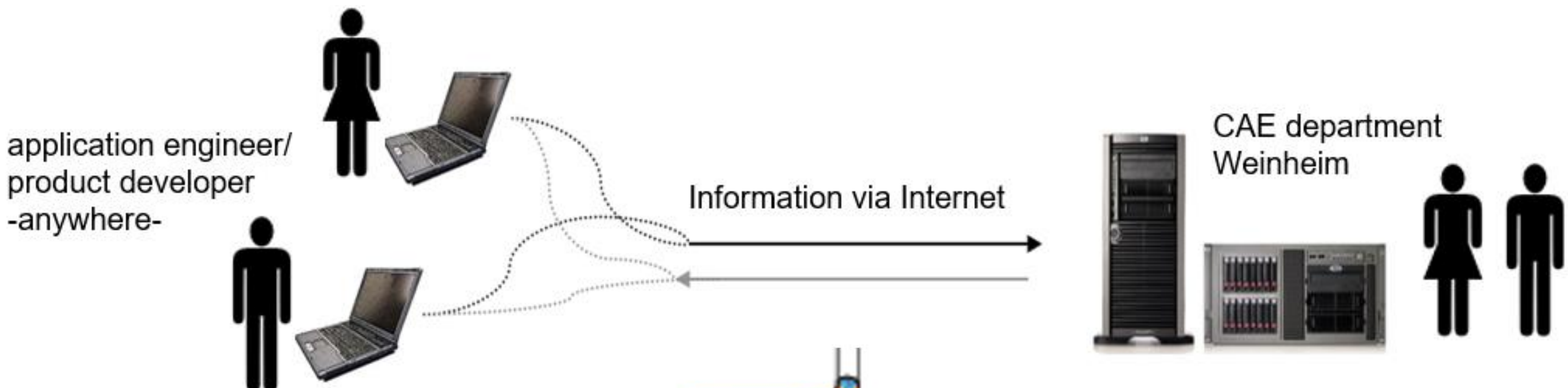
Gamez-Montero: Friction effects on the load capacity of a column and a hydraulic cylinder.2008

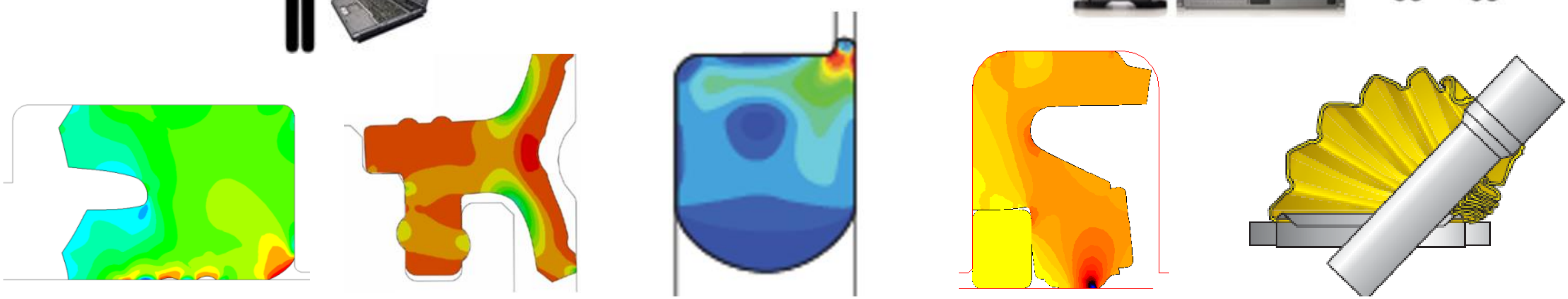
Baragetti / Villa: Effects of geometrical clearances, supports friction and wear rings on hydraulic actuators bending behavior. 2015

Freudenberg Web Based FEM System “WebFEM“

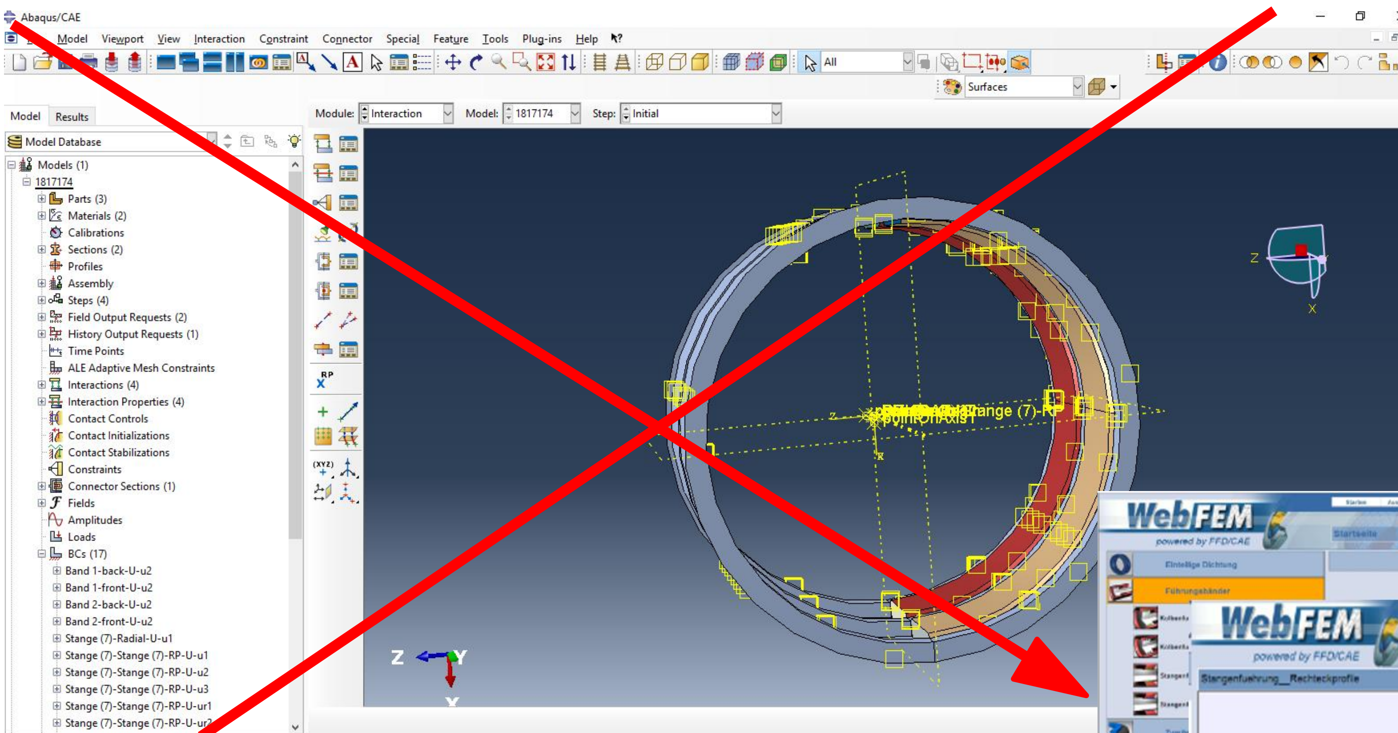
Every FREUDENBGERG - application engineer / product developer worldwide has the possibility to access an internet-based FEM system “WebFEM“.

By entering some defined system parameters and input variables, the developer is able to simulate the behaviour of specific products without special FEM knowledge. E.g. There are tailor made modules available for: ▶reciprocating seals, ▶radial seals, ▶diaphragms, ▶bellows, ▶custom moulded products and the subject of this presentation: **▶guide elements.**

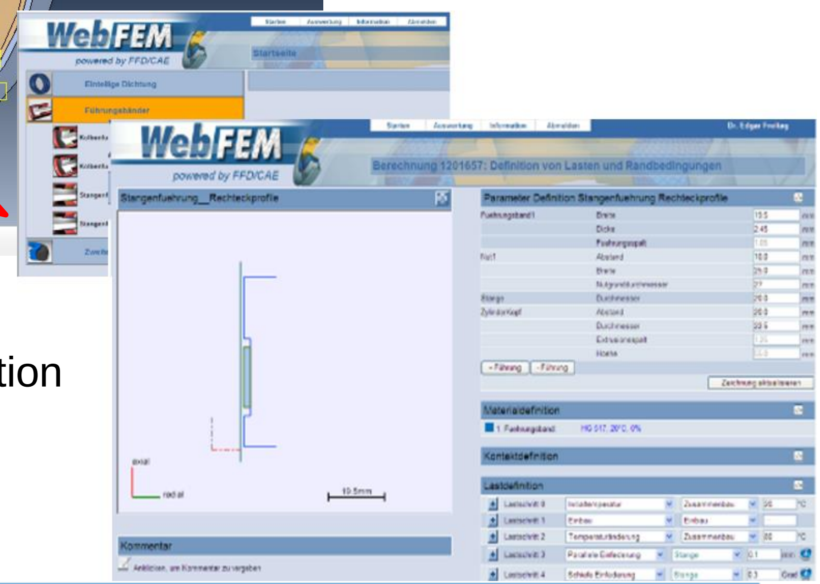




Freudenberg WebFEM Guide Ring System

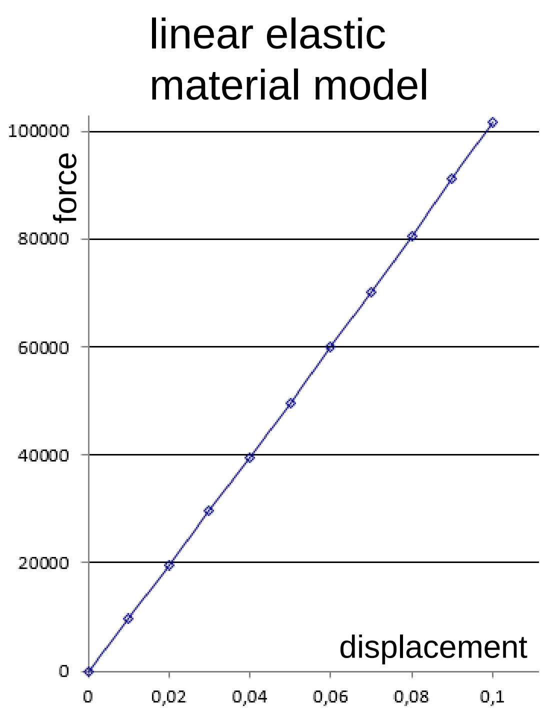


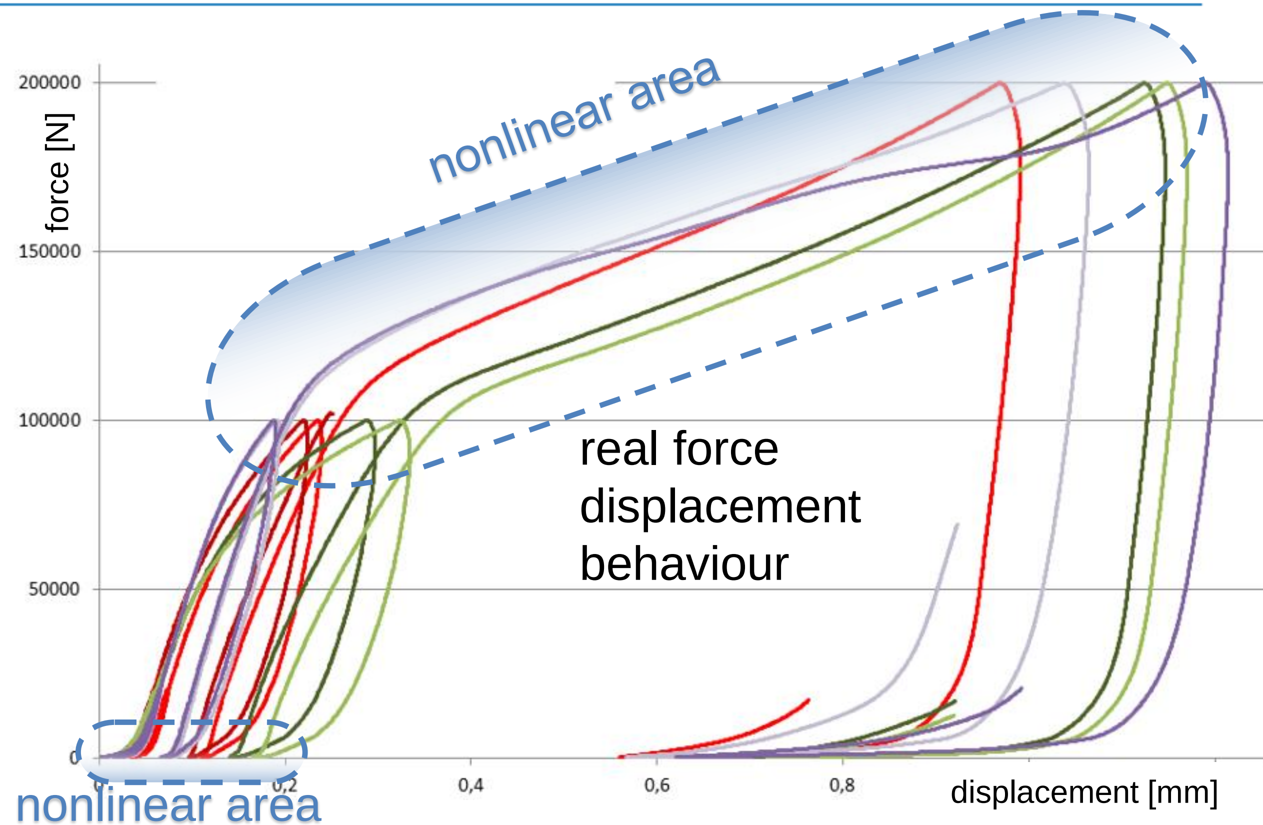
The user is guided through parameterized input masks. Special knowledge to operate the ABAQUS software is not necessary.



With knowledge of geometrical dimensions, angular displacement, max. allowable radial compression/deflection of the guide rings and the installation layout, the loading capacity of the guide elements can be calculated for parallel and angular displacement.

Linear Elastic vs Real Behaviour



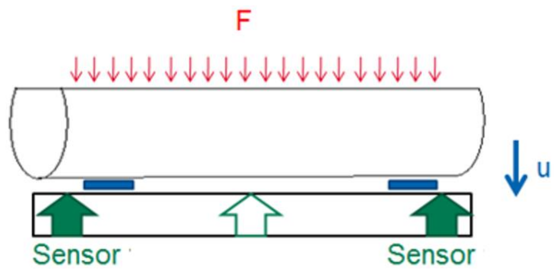


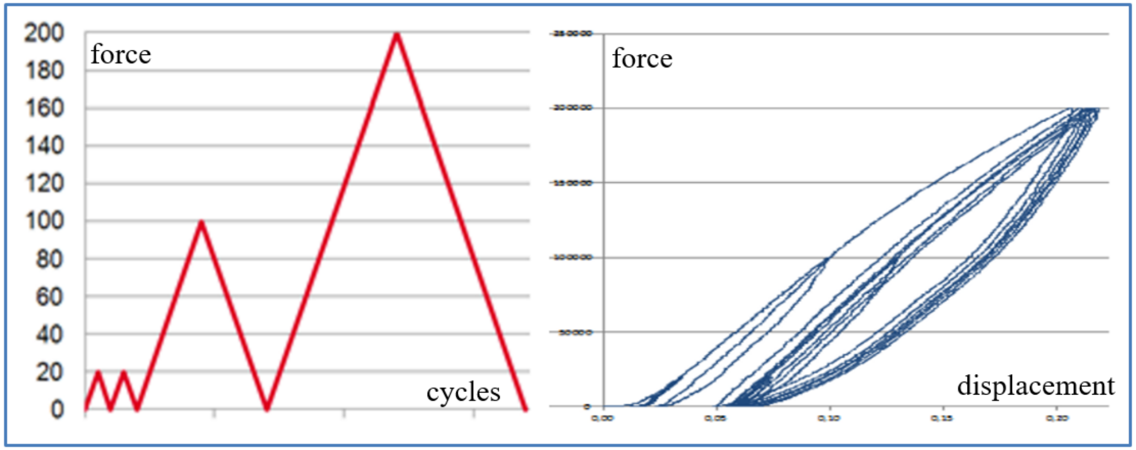
Overloaded Nylon / PA (reinforced)

Overloaded phenolic (fabric-base laminate)

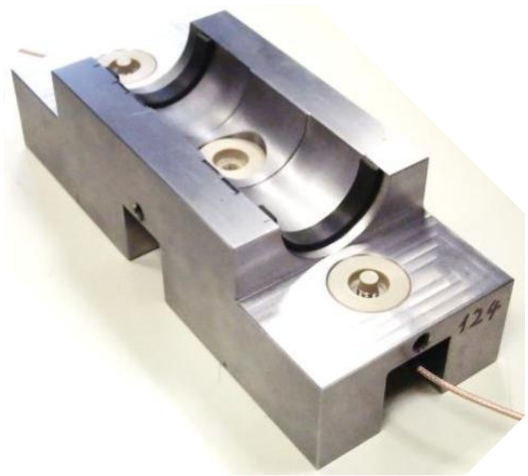
Testing Principles

More than 150 compression tests were carried out, using 20 different materials and 10 different geometries of guide rings. We tested a lot of different load intervals, dimensions, processing variants and surfaces.





Example load cycles and typical force-displacement diagram



Changeable fixture device with housings according to DIN ISO 10766 e.g. 45 x 50 x 9,7 and 45 x 50 x 5
Load: variable up to 200 kN (23°C)
Temperature: 23°C / 80°C (20kN)

Sensors measure guide rings deformation.

Material Nonlinearities

The objective was first to simulate the tested product behavior as close to reality as possible but with the requirement of using a material model that is available as standard in ABQUS.

The test results showed a pressure dependent plastification beyond the linear region and another nonlinearity at the start of the loading.

Unfortunately material models which are available in ABAQUS and consider pressure dependent plastification like

- Cam-Clay- Model
- Drucker-Prager-Model
- Gurson-Model
- Crushable-Foam-Model

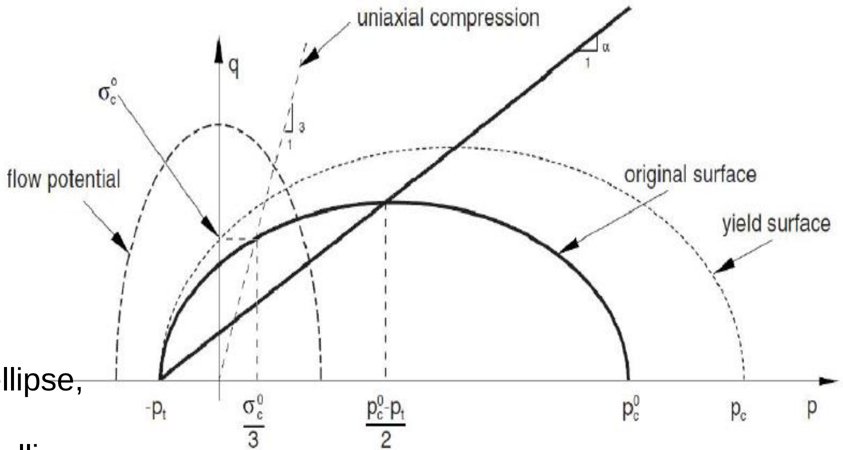
were not sufficient (without adjustments) for the solution of the whole set of problems. First we had to select the plasticity model for the pressure dependency.

In ABAQUS, the crushable foam model showed the best numerical stability and was able to simulate the nonlinearity with high pressure.

The Crushable Foam Model

Yield surface

The yield surface for the volumetric hardening model is defined as



$$F = \sqrt{q^2 + \alpha^2 (p - p_0)^2} - B = 0,$$

where $p = -\frac{1}{3}\mathrm{trace}\,\boldsymbol{\sigma}$ is the pressure stress,

$q = \sqrt{\frac{3}{2}\,\mathbf{S}:\mathbf{S}}$ is the Mises stress,

$\mathbf{S} = \boldsymbol{\sigma} + p\,\mathbf{I}$ is the deviatoric stress,

A is the size of the (horizontal) p-axis of the yield ellipse,

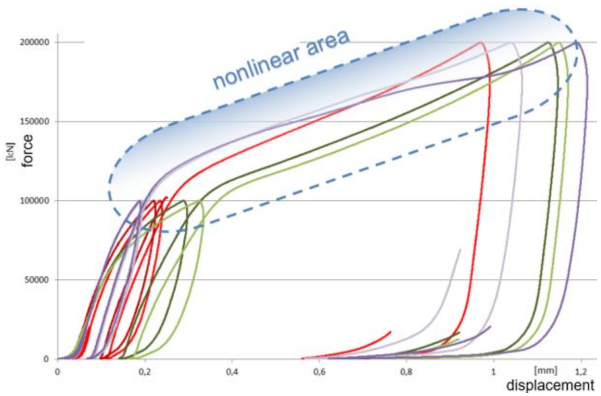
$B = \alpha\ A = \alpha\ \frac{p_c + p_t}{2}$ is the size of the (vertical) q-axis of the yield ellipse,

$\alpha = B/A$ is the shape factor of the yield ellipse that defines the relative magnitude of the axes,

$p_0 = \frac{p_c - p_t}{2}$ is the center of the yield ellipse on the p-axis,

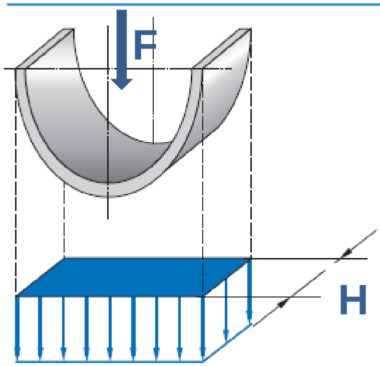
p_t is the strength of the material in hydrostatic tension, and

p_c is the yield stress in hydrostatic compression (always positive).



The yield surface evolves in a self-similar fashion (constant α); and the shape factor can be computed using the initial yield stress in uniaxial compression, σ_c^0 , the initial yield stress in hydrostatic compression, p_c^0 (the initial value of p_c), and the yield strength in hydrostatic tension, p_t : $\propto = \frac{3k}{\sqrt{(3k_t + k)(3 - k)}}$ with $k = \frac{\sigma_c^0}{p_c^0}$ and $k_t = \frac{p_t}{p_c^0}$

Geometry/Surface → Macroscopic View



F = P x A; A = d x H; H = F / (d x P)

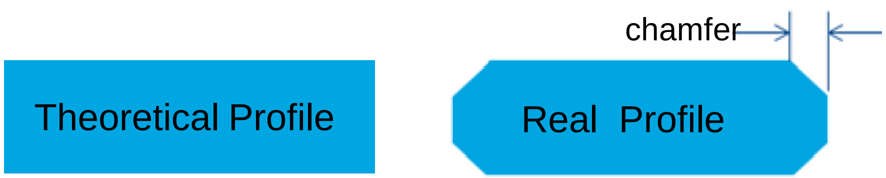
H = guide strip width [mm]

F = transverse load [N]

A = projected area [mm^2]

P = permissible surface pressure [N/mm^2]

d = nominal diameter of rod or piston [mm]



Example: chamfer 0,5mm x 45°, x 2

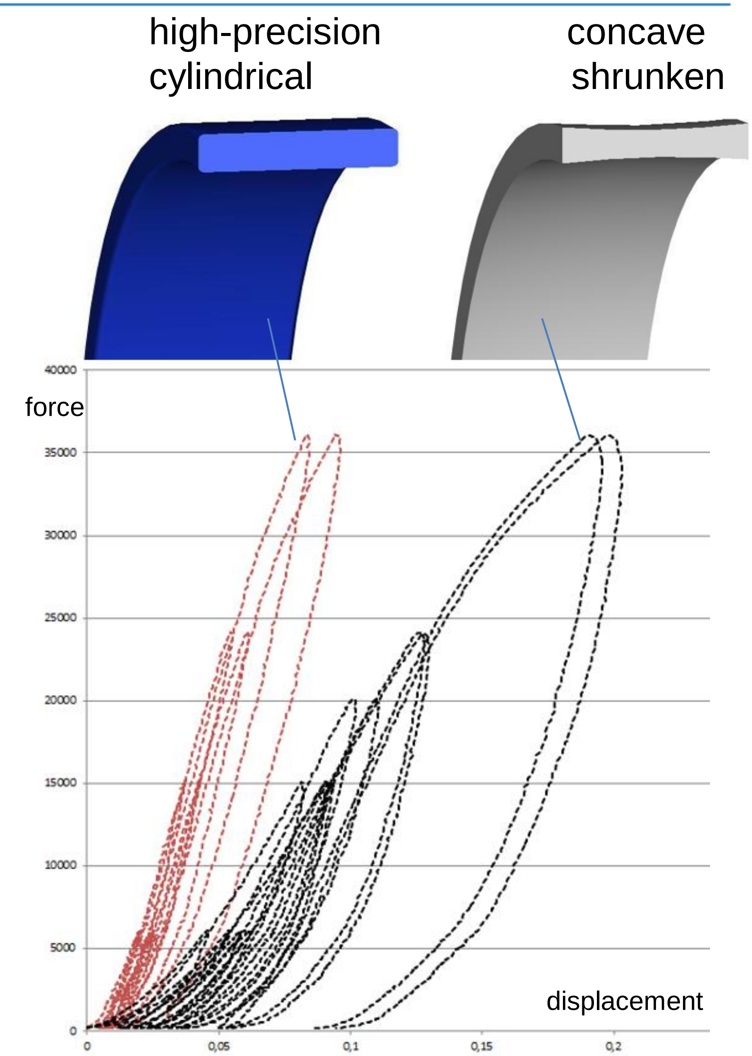
width share of chamfers in %

24,5 mm → 4,1%

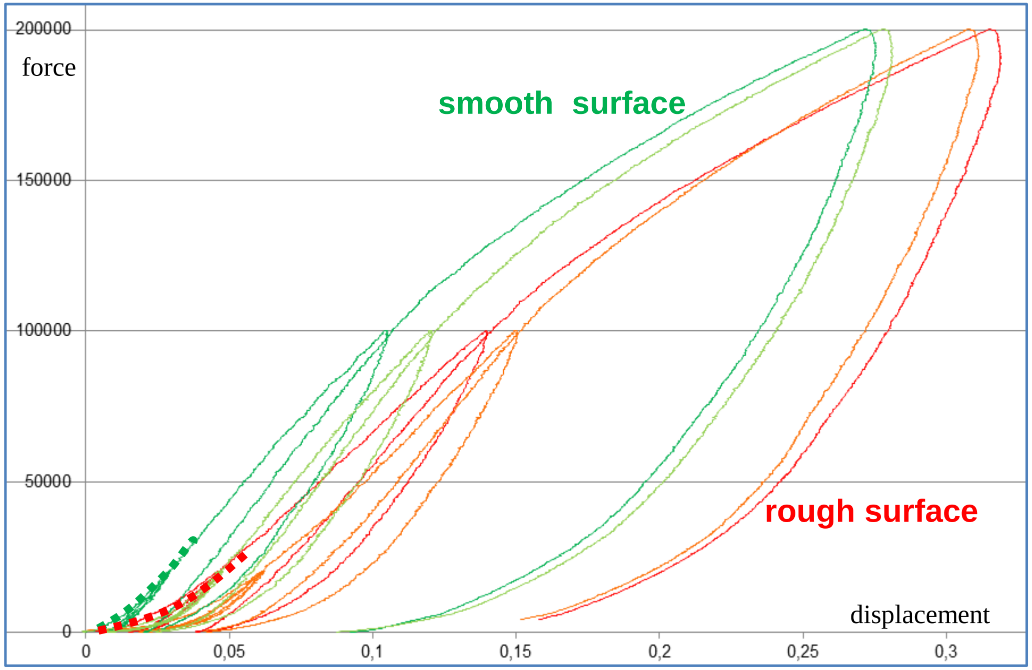
14,8 mm → 6,8%

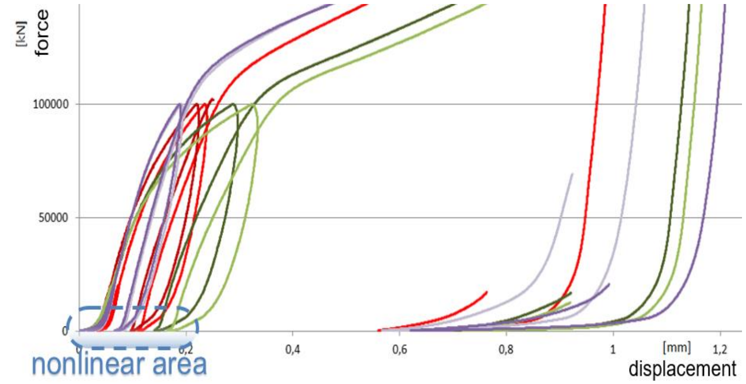
9,6 mm → 10,4%

5,5 mm → **18,2 %** reduction of projected contact area

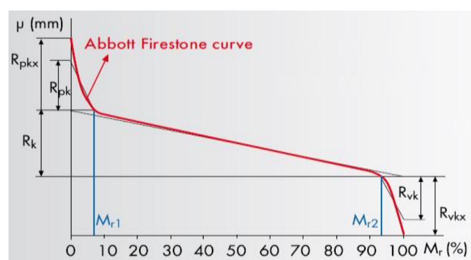


Surface Properties → Microscopic View



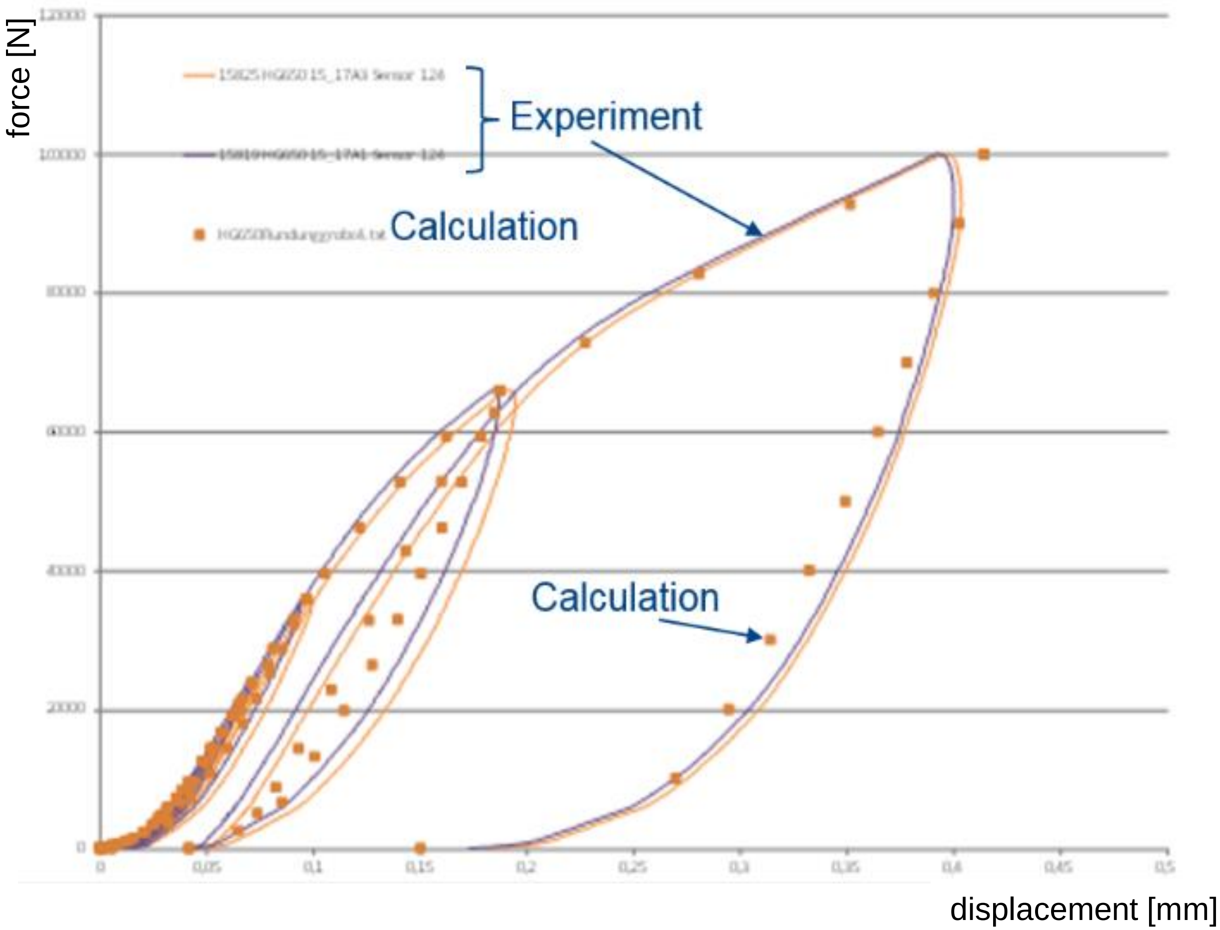


In special test series, surface changes before and after loading were examined in detail for different guide rings. Furthermore, specially magnified surrogate geometries were manufactured and examined before and after the pressure load.



A theoretical approach was discussed with the aim to allow conclusions from surface measurement, roughness parameters and bearing ratio.

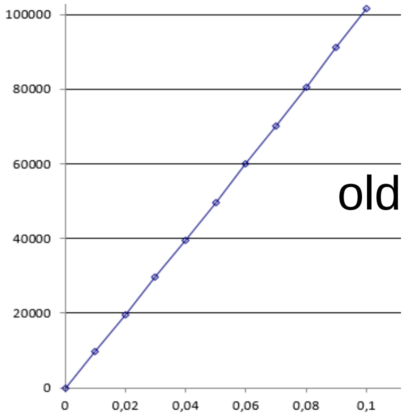
New Freudenberg Material Model for Guide Rings



Example of verification:

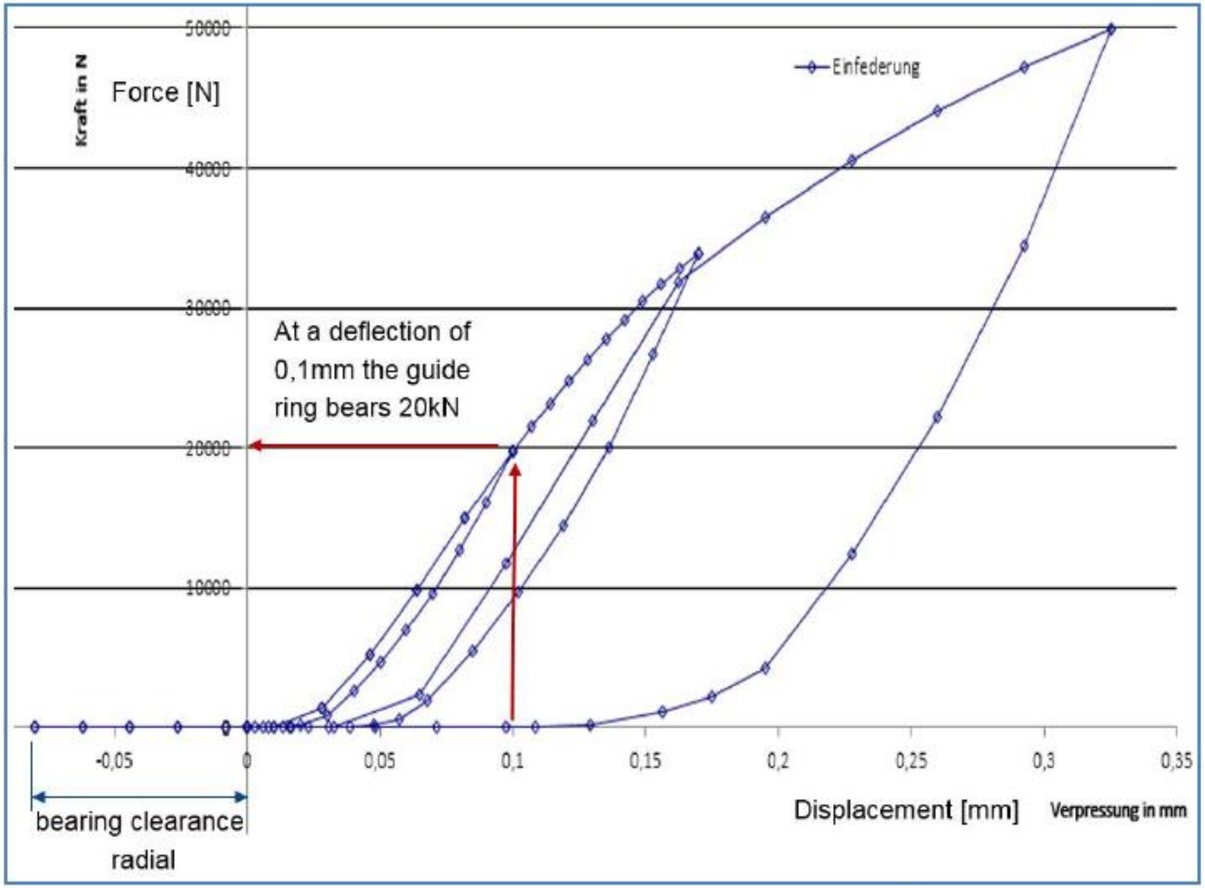
Experiment vs WebFem-calculation with 3 load cycles

New Freudenberg Material Model for Guide Rings



new

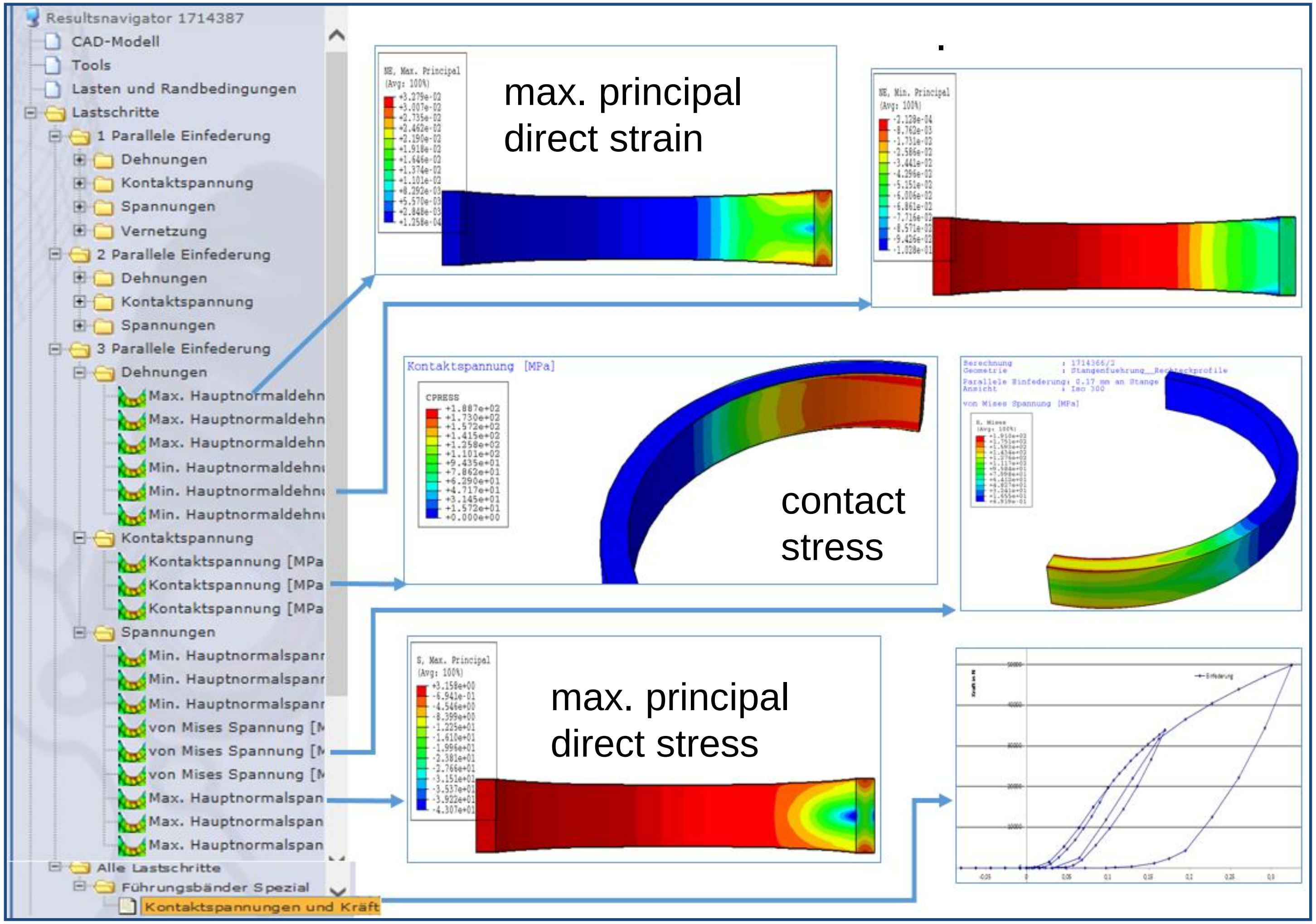
WebFEM output example of load bearing capacity



WebFEM output example for 3 cycles with displacement of

- 0,1mm
- 0,17mm
- 0,33mm

Output Examples



min. principal direct strain

mises stress

force-displacement diagram

Status, Summary and Conclusion

Current Status

Linear elastic model

parallel deflection: available / angular displacement: available / rectangular profile: available

Guivex profile: available / different temperatures: available

New material model

parallel deflection: available / angular displacement: phase of validation / rectangular profile: available

Guivex profile: available / different temperatures: available end 2018 / chamfer definition: available

free geometry interface: available end 2018

Summary and Conclusion

Within the Freudenberg Group, every application engineer / product developer worldwide has the opportunity to access the online FEM system "WebFEM".

Among other products, synthetic guide rings can be calculated parametrised.

The relevant material model has been further developed so that also the non-linear behaviour of various guide elements and materials can be simulated realistically.

Consequently it is possible in future to make more accurate predictions regarding stresses, strains and load capacity.

With an optimal design, selection and utilization of the products, it could be possible e.g. to reduce the size or number of guide elements in a cylinder and to save installation space or cylinder length. These improved design options ultimately can lead to cost advantages for the cylinder manufacturer.

Thank you for your attention!

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